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ENGELMANN SPRUCE IN THE ROCKY MOUNTAINS,

WITH SPECIAL REFERENCE TO GROWTH, VOLUME, AND REPRODUCTION.

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ENGELMANN SPRUCE IN THE ROCKY MOUNTAINS, WITH SPECIAL REFERENCE TO GROWTH, VOLUME, AND REPRODUCTION.

Engelmann spruce forms the spruce type of forest in the Rocky Mountains. With its chief associates it composes dense stands close to timber line, at the headwaters and along the upper courses of streams. These forests retard the melting of snows and the run-off from precipitation, and at the same time protect the soil from drying out and from erosion. In approach to true forest conditions few other forest types in the region rival these stands and no other type equals them over so large an area in the higher altitudes. Their protective value is proportionately great.

ECONOMIC IMPORTANCE.

Moreover, when the more valuable species of the region—yellow pine and Douglas fir—are lacking, Engelmann spruce timber has considerable commercial importance; so that the value placed upon it and the extent to which it is used depend not so much on its quality as on the availability of other and better timber. The annual lumber cut is not large; in 1908 it was 37,801,000 feet, board measure, about 3.5 per cent of the total cut of the region, and of this amount, 21,431,000 feet, or 57 per cent, came from Colorado.

The lumber is rarely clear and is not durable in contact with the soil, but it finds many uses in protected places as construction material. It is also used for mine timbers, railroad ties, posts, and poles of all kinds.

DISTRIBUTION AND LOCAL OCCURRENCE.

RANGE.

Engelmann spruce grows from Yukon Territory south through British Columbia, Washington, and Oregon to the California line and throughout the Rocky Mountains south to Arizona and New Mexico. So far as known it attains the largest size and the greatest density in the provinces of Alberta and British Columbia. In the south it is confined to high altitudes, while in the north stronger competitors crowd it out from areas which offer suitable conditions of soil and climate. Over the greater part of the range it grows in small bodies, almost always in mixed stands, except in the south.

In common with other species of wide latitudinal distribution, Engelmann spruce occupies progressively higher altitudes from its northern to its southern limits. The general climatic features are perhaps fairly uniform throughout its range.

The spruce type is usually subject to heavy snowfall and extensive drifting. In a few places the timber line is lowered by late-lying snow banks. The mean annual precipitation is not known, though observations in the high mountains of the region give an average of over 30 inches per annum at 14,000 feet elevation.

The temperature rarely exceeds 90° F., while the minimum is frequently as low as −25° F.

As a rule the growing season is limited to the three months of June, July, and August; in protected situations, however, it may be of somewhat longer duration. Near timber line it is shortened to about eight weeks. Throughout its range severe frosts usually occur every month in the year except July and August.

ASSOCIATED SPECIES AND TYPES.

The commonest, and in many stands the only, associate of Engelmann spruce is alpine fir, which is often abundant in the small sizes, and particularly in the young growth. Alpine fir is practically as tolerant as Engelmann spruce, and is less exacting as to seed-bed conditions, so that it often reproduces better. In many spruce forests lumbering will leave the ground mainly in possession of alpine fir, at least for one rotation.

Table 1 shows the number and proportion of spruce and alpine fir over 15 inches in diameter, breast-high, on 10 plots in virgin stands of the Engelmann spruce type in Colorado. It can be seen that between these two Engelmann spruce forms three-fourths of the stand.

TABLE 1.—*Comparison of Engelmann spruce and alpine fir in mixed stands in Colorado.*

Trees 15 inches and over per acre.	Engelmann spruce trees per acre.		Alpine fir trees per acre.	
Number:	*Number.*	*Per cent.*	*Number.*	*Per cent.*
124	64.0	51.0	60.0	49.0
76	40.0	52.0	36.0	48.0
160	110.0	68.0	50.0	32.0
91	75.0	82.0	16.0	18.0
85	80.0	94.0	5.0	6.0
40	40.0	100.0	0.0	0.0
52	34.0	65.0	18.0	35.0
85	68.0	80.0	17.0	20.0
66	57.0	86.0	9.0	14.0
37	27.0	73.0	10.0	27.0
Average (81.6)	59.5	75.1	22.1	24.9

Lodgepole pine ranks next after alpine fir as an associate of spruce. This tree owes its prominence in the spruce type largely to fires, which create conditions that temporarily favor it and so encourage it to come in on the lower edges of the spruce stands. The association of lodgepole pine and spruce marks, however, a transition type. There is either an understory of spruce, or else an intermixture of large spruce with pine that is mainly mature; and in both cases the ground will revert to spruce in time.

At the lower elevations and on dry exposures, throughout the spruce type, a part of the mixture is formed by Douglas fir, which ranks perhaps third among the associates of spruce. Species which less commonly grow with spruce are bristle-cone pine and limber pine. In the southern Rockies bristle-cone pine grows within the spruce type on dry ridges and south slopes, though for the most part it occupies distinct areas. At the lower limits of the spruce, limber pine is more abundant in mixture than is bristle-cone pine, but in many places the lower altitudinal range of limber pine prevents its becoming an important associate of spruce.

Many other species form occasional, less important mixtures with Engelmann spruce throughout its wide range. In northern Montana and Idaho conditions differ markedly from those elsewhere in the Rocky Mountain region; there are many more species, of which the majority enter to some extent into mixture with spruce. There, besides its common associates alpine fir, lodgepole pine, and Douglas fir, are alpine larch and white-bark pine at high elevations and occasionally western white pine, lowland fir, western larch, western hemlock, and giant arborvitæ at the lower elevations. In northern Washington there are a few pure stands, but mixtures with the various species common to the upper altitudes of that region are the rule. In the Cascade Range in Oregon spruce occurs with alpine, noble, and white fir, as well as with mountain hemlock, lodgepole pine, and Douglas fir. In the lower part of the spruce zone aspen is common, either as a mixture or as an upper story, but it is never a competitor. It is rather an aid, for it protects the soil, while its shade is too light to hinder the growth of the spruce.

Only in the southern part of its range is spruce the predominating tree over large areas, and even there alpine fir usually makes up from 20 to 50 per cent of the stand. Spruce stands are most nearly pure at the heads of gulches, in narrow strips along the banks of streams, and on the upper slopes near timber line.

A fairly distinct type of lodgepole pine is found near the southern end of the lodgepole range, where it grows in mixture with spruce. Quite generally throughout the Rocky Mountains the spruce-Douglas fir mixtures form a separate type covering small areas at the lower altitudinal limit of the spruce.

DENSITY OF STANDS.

Spruce averages about 5,000 feet, board measure, per acre, and rarely exceeds 30,000 feet. Occasionally on limited areas overmature stands contain 50,000 feet per acre. The heaviest stands are along the upper courses of streams and at the heads of gulches on north exposures. Most of the commercial timber is in the southern and central Rockies, where there are rather large, continuous bodies.

Elsewhere throughout the Rocky Mountains small bodies of spruce, with timber of excellent quality, are common at the heads of gulches, along streams, and on high, flat plateaus. These are, however, disconnected, and form only a part of the total stand of the forests in which they are located.

SILVICAL CHARACTERISTICS.

Engelmann spruce presents very definite characteristics of form and habit. Its requirements, however, are not rigidly fixed. Thus, abundance of soil moisture and a rich soil may compensate for a decreased amount of light, and a warm soil for a low air temperature.

MOISTURE, LIGHT, AND SOIL REQUIREMENTS.

The determining factor for the Engelmann spruce type is moisture, both of the soil and of the air. For this reason whatever contributes to the maintenance of proper moisture conditions in the soil is important. Temperature and aspect are necessarily important, for these affect the amount of precipitation and its conservation. Altitude, by controlling the temperature, and thus precipitation, is often the key to the situation. The character of the soil and the drainage conditions may be instrumental in conserving the soil moisture and extending the type locally, but the bulk of Engelmann spruce is confined to high altitudes, where low temperatures induce greater precipitation.

Throughout its range Engelmann spruce is more tolerant than any of its associates, with the possible exception of alpine fir. While it responds readily to light, and grows well in the open in the seedling stage when sufficient soil moisture is present, yet some shade does not prevent its development. The seedlings and young trees will endure long suppression, and when released will recover rapidly and make good growth. It is a common thing for the majority of spruce trees under natural forest conditions to be held back from thirty to fifty years by suppression; it thus forms a reserve, under the dense shade of the mature stand.

The physical condition of the soil, rather than its composition, is of the first importance, though there are some indications that, other conditions being equal, Engelmann spruce reaches its maximum height and diameter growth on limestone soils. Where gravel or bowlders are mixed with the soil this changes its physical character and therefore its capacity for retaining moisture. Swampy situations are good unless the soil is sour, but in the seedling stage growth is sometimes slower in swampy places than on the slopes.

ROOT SYSTEM.

Though the root system of Engelmann spruce is superficial, it is so well developed that, except in rare cases, the tree is wind firm. In the seedling stage there is a taproot, but after the tree reaches a height of 20 feet this root usually ceases to develop. As a rule, the

mature trees have several very strong lateral roots with a radius of 20 feet or more, which do not, however, extend more than 2 feet below the surface of the ground.

This root system enables the spruce to thrive on shallow soils and gives it the advantage on new soils. On the other hand, it makes the tree dependent upon superficial soil moisture, and exposes it to injury from even light surface fires and, on thin soils in exposed places, to wind throw.

Table 2 gives the average height for each diameter class in typical situations.

TABLE 2.—*Height by diameter classes; Engelmann spruce in Colorado and Utah.*

Diameter breast-high.	Height.	Basis.	Diameter breast-high.	Height.	Basis.	Diameter breast-high.	Height.	Basis.
Inches.	*Feet.*	*Trees.*	*Inches.*	*Feet.*	*Trees.*	*Inches.*	*Feet.*	*Trees.*
7	44	5	16	82	60	25	100	9
8	50	11	17	84	58	26	101	13
9	55	19	18	87	54	27	102	5
10	60	19	19	89	45	28	103	7
11	64	34	20	91	43	29	104	4
12	69	43	21	93	41	30	105	4
13	73	43	22	95	26	31	106	3
14	76	52	23	97	23			
15	79	37	24	98	23			681

Table 3 shows the diameter of trees inside the bark at 10-foot intervals. It is based on measurements of 681 trees in Colorado and Utah at elevations of between 10,000 and 11,000 feet.

TABLE 3.—*Taper of Engelmann spruce in Colorado and Utah.*

Diameter breast-high outside bark.	HEIGHT—FEET.											Total height.	Basis.
	1.5.	10.	20.	30.	40.	50.	60.	70.	80.	90.	100.		
	DIAMETER INSIDE BARK—INCHES.												
Inches:												*Feet.*	*Trees.*
7	7.2	6.4	5.5	4.2	1.7	.....	.....	.....	.....	.....	.....	44	5
8	8.4	7.2	6.3	5.1	2.9	.....	.....	.....	.....	.....	.....	50	11
9	9.6	8.1	7.1	5.9	4.2	1.6	.....	.....	.....	.....	.....	55	19
10	10.9	9.1	7.9	6.7	5.1	3.0	.....	.....	.....	.....	.....	60	19
11	12.2	9.9	8.7	7.5	6.0	2.8	1.2	.....	.....	.....	.....	64	34
12	13.3	10.8	9.5	8.3	6.9	4.9	2.5	.....	.....	.....	.....	69	43
13	14.4	11.8	10.3	9.0	7.6	5.8	3.7	1.0	.....	.....	.....	73	43
14	15.5	12.6	11.1	9.8	8.4	6.7	4.8	2.1	.....	.....	.....	76	52
15	16.5	13.5	11.9	10.6	9.2	7.5	5.5	3.0	.....	.....	.....	79	37
16	17.4	14.3	12.7	11.3	10.0	8.4	6.5	3.9	0.8	.....	.....	82	60
17	18.5	15.2	13.4	12.0	10.7	9.2	7.3	4.9	1.6	.....	.....	84	58
18	19.6	16.2	14.2	12.7	11.4	9.8	7.9	5.4	2.3	.....	.....	87	54
19	20.6	17.0	15.0	13.4	12.0	10.4	8.5	6.1	3.0	.....	.....	89	45
20	21.5	17.9	15.8	14.2	12.8	11.0	9.1	6.7	3.7	0.4	.....	91	43
21	22.4	18.7	16.6	15.0	13.5	11.6	9.6	7.3	4.4	1.1	.....	93	41
22	23.2	19.5	17.4	15.7	14.1	12.3	10.2	7.9	5.0	1.8	.....	95	26
23	24.0	20.3	18.1	16.4	14.8	12.9	10.8	8.5	5.6	2.4	.....	97	23
24	25.0	21.1	18.9	17.2	15.5	13.5	11.4	9.0	6.2	3.0	.....	98	23
25	26.0	22.0	19.7	17.9	16.2	14.2	11.9	9.6	6.8	3.5	.....	100	9
26	27.0	22.9	20.5	18.7	16.9	14.8	12.5	10.1	7.3	4.0	0.4	101	13
27	28.0	23.8	21.3	19.2	17.6	15.5	13.1	10.6	7.8	4.4	.8	102	5
28	29.2	24.7	22.1	20.2	18.3	16.1	13.6	11.1	8.2	4.8	1.2	103	7
29	30.4	25.6	22.9	21.0	19.0	16.8	14.2	11.6	8.6	5.2	1.6	104	4
30	32.0	26.6	23.7	21.8	19.7	17.5	14.9	12.1	9.0	5.6	1.9	105	4
31	33.8	27.5	24.5	22.6	20.6	18.2	15.5	12.6	9.4	5.9	2.3	106	3
Total	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	681

HABIT.

The most conspicuous feature in the general appearance of Engelmann spruce is the crown. This is heavy and close, and except in the densest stands extends well downward on the bole. The density of the crown is due to the large number of branches and to the fact that the needles often persist from ten to fifteen years. In good situations it is usually spire-shape, narrow, and compact, though in overmature trees it is broader and more irregular; the less favorable the situation the broader and more irregular it becomes.

Like other trees, Engelmann spruce varies in form with the situation. As a rule there is considerable taper, except in dense stands in the best situations. Many trees are ideal in shape for telephone and telegraph poles. The best trees are commonly found in deep, moist gulches well within the spruce zone, and on north slopes in dense stands, and in these situations the taper of the second and third logs is scarcely noticeable in the standing tree. Near timber line the taper is very rapid and the trees are shorter. Sometimes trees with a diameter of 8 or 10 inches are only 15 or 20 feet high.

Engelmann spruce has a comparatively thin bark, and is therefore very easily damaged by fire. The bark is, as a rule, distinguished by its thin and round or oval scales, which gradually become detached and are replaced by others. Young trees, however, have a thin, unbroken bark, often with resin vesicles or "blisters," like those found on balsams and on Douglas fir, but less numerous and less conspicuous. The blisters are obscured by being more deeply sunken in the bark, and usually disappear early in the life of the tree. In a few cases they are very prominent, but they are never so marked as in the balsams.

In good situations the average size of Engelmann spruce varies from 80 to 100 feet in height and from 20 to 30 inches in diameter, though individual trees 5 feet in diameter and 130 feet or more in height are found in Colorado. In northern Idaho and Washington it is said to reach 3 feet in diameter and 140 feet in height, and in Canada 5 feet in diameter and over 160 feet in height. The large sizes, however, are very uncommon in the Rocky Mountains. In all except the very best situations, a diameter of from 18 to 22 inches may be taken as the average for mature trees.

GROWTH.

Engelmann spruce grows rather slowly, except when light conditions are favorable throughout its entire life, which is rarely the case in the usual uneven-aged stands. Its growth is, however, persistent and enables it to outstrip two of its common associates, alpine fir and lodgepole pine.

It often attains a diameter of 12 inches at an age of from 125 to 150 years. In many cases trees 18 inches in diameter show only 150 rings on the stump; such trees, however, are usually about 200 years old, since they may have started under a more or less dense cover, and have taken from forty to sixty years to reach stump height. Trees from 18 to 22 inches in diameter are more often 200 to 250 years old than less. The usual age of the large-sized trees ranges from 200 to 300 years, and the age limit for the species is about 400 years.

The diameter growth of Engelmann spruce is shown in Table 4, which gives the breast-high diameter at ten-year intervals. The table is based on the measurement of 87 stumps 2 feet high in National Forests in Colorado and Utah. Above 200 years of age the growth becomes too irregular to yield reliable figures. The figures show that diameter growth is greatest between the ages of 40 and 120 years, and that below 40 years it is exceedingly slow. Since Engelmann spruce reaches its maturity at not over 300 years, trees from 350 to 400 years of age are all overmature, and their growth has long been nearly at a standstill.

TABLE 4.—*Diameter growth of Engelmann spruce.*

Age.	Diameter breast-high.	Age.	Diameter breast-high.	Age.	Diameter breast-high.	Age.	Diameter breast-high.
Years.	*Inches.*	*Years.*	*Inches.*	*Years.*	*Inches.*	*Years.*	*Inches.*
40	0.8	90	5.2	140	9.4	190	12.9
50	1.6	100	6.2	150	10.1	200	13.7
60	2.5	110	7.0	160	10.8		
70	3.4	120	7.9	170	11.5		
80	4.3	130	8.6	180	12.2		

Table 5 shows the rate of height growth and embodies the results of 450 sectional age counts on 104 trees in the National Forests of Colorado and Utah. It may be seen that the greatest growth in height is between the seventieth and one hundred and fiftieth years of age.

TABLE 5.—*Height growth of Engelmann spruce.*

Age.	Height.	Age.	Height.	Age.	Height.	Age.	Height.
Years.	*Feet.*	*Years.*	*Feet.*	*Years.*	*Feet.*	*Years.*	*Feet.*
20	3.8	90	22.0	160	63.0	230	83.0
30	5.1	100	29.0	170	66.0	240	85.0
40	6.2	110	36.0	180	69.0	250	88.0
50	7.4	120	43.0	190	72.0	260	90.0
60	9.0	130	50.0	200	75.0		
70	12.0	140	55.0	210	78.0		
80	16.0	150	60.0	220	80.0		

Table 6 shows the volume growth of trees from 110 to 200 years old, for the entire stems, exclusive of bark. The data were collected from the National Forests of Colorado and Utah.

TABLE 6.—*Volume growth of Engelmann spruce.*

Age.	Entire stem (exclusive of bark).	Scribner Decimal C scale.	Age.	Entire stem (exclusive of bark).	Scribner Decimal C scale.	Age.	Entire stem (exclusive of bark).	Scribner Decimal C scale.
Years.	*Cubic feet.*	*Board feet.*	*Years.*	*Cubic feet.*	*Board feet.*	*Years.*	*Cubic feet.*	*Board feet.*
110	5.8	15	150	15.1	44	190	29.1	107
120	7.9	20	160	18.0	56	200	33.5	129
130	10.1	26	170	21.3	70			
140	12.5	34	180	25.0	87			

WOOD.

The wood of Engelmann spruce is very light in weight, pale yellow in color, very close and usually straight grained, even textured, and easily worked; it shows no distinct boundary between the spring and summer growth. Heartwood and sapwood are so nearly of the same color that it is difficult to distinguish between them. As a rule, heartwood is not formed until the tree reaches an age of from 70 to 100 years. It is weaker and less durable than Douglas fir, and is, therefore, not well adapted to heavy construction purposes, but it is much superior to alpine fir. Its strength under crushing tests is very nearly the same as that of red spruce in the Northeast. The lumber should be seasoned slowly in order to avoid checking and warping.

DANGERS AND DISEASES.

Engelmann spruce is extremely susceptible to fire damage, even by light surface fires. A large percentage of the older matured Engelmann spruce may suffer severely from the ravages of the Engelmann spruce beetle and the death of much timber hitherto attributed to fire has undoubtedly been caused by it. This beetle is by far the most important insect enemy of the spruce and the methods outlined for its control [a] should prove effective in combating it and therefore should be vigorously carried out.

Another injury of less importance is due to a moth whose larvæ live in the cones and feed on the seed. During the season of 1908, the effect of this enemy was very marked in southern Colorado. While not injuring the timber, its tendency is to reduce the seed supply and thus to restrict reproduction.

In the more exposed situations, as on south slopes and steep slopes with thin, rocky soil, Engelmann spruce is injured during seasons of great drought. Ordinary dry seasons do but little damage.

[a] For a general account of the Engelmann spruce beetle, see Bulletin No. 83, Part I, Bureau of Entomology, U. S. Dept. of Agriculture, pp. 126–132, 1909.

REPRODUCTION.

Engelmann spruce reproduces almost wholly from seed. Near timber line, and occasionally elsewhere, it reproduces sparingly from layer shoots from the lower branches. Such growth, however, is of little practical importance.

Under natural conditions suppressed young growth is usually abundant. This can not make progress until openings are made in the forest. The chief effect of lumbering is to release this immature stand, and to stimulate its growth rather than to increase the number of trees present.

Moisture at the surface is the keynote of Engelmann spruce reproduction; and even abundant soil moisture may not suffice if a dry cover of needles or leaves makes it unavailable. Such a condition exists in dense spruce stands on many slopes, and few seedlings are to be found.

Alpine fir seedlings, less exacting as to seed-bed conditions, are often abundant where spruce seedlings are unable to maintain a hold. The apparent reason is that the larger seed of alpine fir contains more plant food, which enables the seedling to produce a rootlet long enough to penetrate the dry soil cover and reach the moisture in the soil. Alpine fir commonly forms over 50 per cent of the new growth in the spruce type, and not infrequently over 90 per cent.

On northern exposures and flats with abundant surface-soil moisture or with the mineral soil exposed, there is a larger proportion of spruce in the reproduction. This is shown particularly in the beds and along the banks of brooks, about upturned roots, and on steep slopes where the vegetable covering has been removed by landslides. The best spruce reproduction noted in Colorado was on steep northern slopes where slides have cleared narrow strips of their timber and top soil, sometimes for hundreds of feet. These exposed places have seeded in to spruce and alpine fir from the side, and in some cases show over 5,000 seedlings per acre, with spruce in the lead.

EFFECT OF FIRE.

Fire has a marked effect upon the Engelmann spruce type. Large burned tracts are often wholly without spruce seedlings, and on many such tracts there is little prospect of reproduction. The main cause of this is lack of seed, though in unfavorable places, such as south slopes, the altered soil conditions are also responsible.

Small areas on north slopes are sometimes greatly benefited by the action of fires which consume the dry mulch and thus prepare the seed bed for reproduction. In such cases the ground is well seeded by

trees near at hand and becomes stocked with from 1,000 to 3,000 seedlings per acre, practically all of which are spruce.

Table 7, based on 139 plots each 10 feet square, gives an idea of the rapidity with which reproduction comes in on burned areas in the Engelmann spruce type where the seed supply is abundant.

TABLE 7.—*Progress of reproduction on burned areas, Engelmann spruce type, Colorado.*

Time since burning.	Engelmann spruce.		Alpine fir.	
	Number.[a]	*Per cent.*	*Number.*[a]	*Per cent.*
First five years	2.53	50	0.06	9
Second five years	1.08	19	.20	31
Third five years	.78	15	.19	30
Fourth five years	.57	11	.10	16
Fifth five years	.14	3	.04	6
Sixth five years	.06	2	.05	8
Total	5.06	100	.64	100

[a] Average number of seedlings per 100 square feet.

The totals are equivalent to 2,204 Engelmann spruce and 279 alpine fir seedlings per acre.

From Table 7 it is apparent that spruce seedlings come in much earlier than alpine fir on burned ground. Spruce reproduction is best in the first five years and then rapidly decreases, while alpine fir reproduction is best in the second and third five-year periods and then decreases. Only 9 per cent alpine fir comes in during the first five-year period, as against 50 per cent spruce in the same period. Thirty years after the area was burned the proportion of alpine fir in the reproduction is only 12.6 per cent. The facts indicate that immediately after the ground is burned over it is not suited to alpine fir, whereas it is excellently suited to spruce.

According to the average in the table, over 1,000 spruce seedlings per acre come in during the first five years, or nearly enough to restock the ground.

On the flats there is usually more moisture and, consequently, more reproduction. Table 8, based on 20 plots, shows an interesting comparison of the rates at which Engelmann spruce and alpine fir come in on wet ground. The reproduction of spruce culminates in the third five-year period. During the first five years after cutting only 18 per cent of the final reproduction of spruce comes in, as against 58 per cent of the final reproduction of alpine fir. Since the seed-bed conditions on a wet flat immediately after cutting are often similar to the conditions before the stand is opened, a larger proportion of alpine fir seedlings is to be expected at first than on a burned area. The results of the count agree perfectly with the usual preponderance of alpine fir reproduction under mature stands.

TABLE 8.—*Progress of reproduction on wet flats, Engelmann spruce type, Colorado.*

Time since cutting.	Engelmann spruce.		Alpine fir.	
	Number.[a]	*Per cent.*	*Number.*[a]	*Per cent.*
First five years	1.60	18	0.70	58
Second five years	1.80	19	.35	28
Third five years	5.65	63	.15	14
Total	9.05	100	1.20	100

[a] Average number of seedlings per 100 square feet.

The change in seed-bed conditions, due directly to the cutting, seems to be the only explanation of the difference in the proportionate number of seedlings of Engelmann spruce and alpine fir at the different periods after cutting. As shown in Table 8, the fir is proportionately more abundant at first, because the thick cover of needles does not so greatly retard it, while the spruce gradually gains ground as the cutting grows older, because the abundant cover of needles decays.

Reproduction on slopes is shown in Table 9, based on 78 plots. On the slopes the spruce seedlings are rather evenly distributed through the first fifteen years, whereas those of alpine fir gradually increase in number until the third five-year period. The proportion of alpine fir which has come in since cutting is 16.8 per cent. There is a much larger proportion of alpine fir in the total reproduction than this, because the bulk of seedlings started before lumbering, when the alpine fir has a great advantage. On most slopes before lumbering alpine fir usually forms over 50 per cent of the reproduction.

TABLE 9.—*Progress of reproduction on dry slopes, Engelmann spruce type, Colorado.*

Time since cutting.	Englemann spruce.		Alpine fir.	
	Number.[a]	*Per cent.*	*Number.*[a]	*Per cent.*
First five years	1.46	36	0.17	25
Second five years	1.19	29	.23	33
Third five years	1.33	32	.29	42
Fourth five years	.11	3	.....	.....
Total	4.09	100	.69	100

[a] Average number of seedlings per 100 square feet.

Tables 10 and 11 show the rate of growth in height of Engelmann spruce and alpine fir seedlings on burned slope and unburned flat and slope in Colorado.

The rate of growth of seedlings exhibits wide variation in the different situations. It is most rapid on burned land and slowest on wet flats. The exceeding slowness of growth of both Engelmann spruce and alpine fir seedlings is the most striking feature in the tables.

At 15 years of age the average height of spruce seedlings is 18.3 inches on burned slope, 12.2 inches on unburned slope, and 8.1 inches on unburned flat. At the same ages and respective locations the

average height growth of alpine fir is 11 inches, 9.8 inches, and 5.8 inches. At the close of the fifteen-year period, spruce shows a 50 per cent increase in rate of growth from flat to unburned slope and a further increase of 50 per cent from unburned slope to burned slope.

TABLE 10.—*Height growth of Engelmann spruce seedlings in Colorado.*

Age.	Burned slope.			Unburned slope.			Unburned flat.		
	Growth last 5 years.	Total height.	Basis.	Growth last 5 years.	Total height.	Basis.	Growth last 5 years.	Total height.	Basis.
Years:	*Inches.*	*Inches.*	*Trees.*	*Inches.*	*Inches.*	*Trees.*	*Inches.*	*Inches.*	*Trees.*
1	.....	0.3	50	.....	0.3	45	.....	0.3	30
2	.....	.6	4	.....	.6	12	.....	.6	10
3	.....	1.1	2	.....	.9	6	.....	.9	20
4	.....	1.6	5	.....	1.3	7	.....	1.3	17
5	.....	2.1	54	.....	1.8	22	.....	1.7	36
6	2.4	2.7	8	2.0	2.3	18	1.8	2.1	18
7	2.8	3.4	11	2.3	2.9	30	2.0	2.6	8
8	3.1	4.2	6	2.7	3.6	19	2.2	3.1	3
9	3.5	5.1	90	3.0	4.3	6	2.4	3.7	4
10	4.1	6.2	29	3.3	5.1	12	2.6	4.3	3
11	4.9	7.6	22	3.7	6.0	12	2.9	5.0	6
12	6.0	9.4	45	4.3	7.2	17	3.1	5.7	8
13	7.5	11.7	138	4.9	8.5	11	3.4	6.5	4
14	9.5	14.6	60	5.8	10.1	15	3.6	7.3	2
15	12.1	18.3	76	7.1	12.2	29	3.8	8.1	9
16	15.0	22.6	8	9.1	15.1	23	3.9	8.9	5
17	18.5	27.9	18	.....	.....	.....	.....	.....	.....
18	23.3	34.0	2	.....	.....	.....	.....	.....	.....
19	26.0	40.6	1	.....	.....	.....	.....	.....	.....
20	30.1	48.4	6	.....	.....	.....	.....	.....	.....
21	34.4	57.0	14	.....	.....	.....	.....	.....	.....
22	38.6	66.5	1	.....	.....	.....	.....	.....	.....
23	42.6	76.6	2	.....	.....	.....	.....	.....	.....
24	46.6	87.2	1	.....	.....	.....	.....	.....	.....
25	49.6	98.0	9	.....	.....	.....	.....	.....	.....
Total	.....	.....	662	.....	.....	284	.....	.....	183

TABLE 11.—*Height growth of alpine fir seedlings in Colorado.*

Age.	Burned slope.			Unburned slope.			Unburned flat.		
	Growth last 5 years.	Total height.	Basis.	Growth last 5 years.	Total height.	Basis.	Growth last 5 years.	Total height.	Basis.
Years:	*Inches.*	*Inches.*	*Trees.*	*Inches.*	*Inches.*	*Trees.*	*Inches.*	*Inches.*	*Trees.*
1	.....	0.5	26	.....	0.5	4	.....	0.3	1
2	.....	1.0	.....	.....	.9	3	.....	.7	.....
3	.....	1.4	.....	.....	1.3	1	.....	1.0	.....
4	.....	1.9	.....	.....	1.6	.....	.....	1.3	.....
5	.....	2.3	1	.....	1.9	2	.....	1.7	2
6	2.5	2.8	2	1.3	2.2	6	0.8	2.1	1
7	2.6	3.4	1	1.6	2.5	4	1.0	2.5	1
8	2.8	4.0	3	2.0	3.0	2	1.1	2.9	2
9	3.1	4.7	4	2.3	3.6	.....	1.3	3.2	3
10	3.4	5.4	.....	2.7	4.2	2	1.5	3.6	.....
11	3.7	6.3	2	3.1	5.1	1	1.7	4.1	1
12	4.2	7.3	2	3.5	6.0	1	1.9	4.5	4
13	4.6	8.4	14	3.9	7.1	1	2.0	4.9	2
14	5.2	9.6	.....	4.4	8.4	.....	2.2	5.4	5
15	5.9	11.0	1	4.9	9.8	4	2.4	5.8	3
16	6.6	12.4	1	5.4	11.3	9	.....	.....	.....
17	7.3	13.8	16	.....	.....	.....	.....	.....	.....
18	8.1	15.2	1	.....	.....	.....	.....	.....	.....
19	8.9	16.7	1	.....	.....	.....	.....	.....	.....
20	9.8	18.2	.....	.....	.....	.....	.....	.....	.....
21	10.6	19.7	1	.....	.....	.....	.....	.....	.....
Total	.....	.....	76	.....	.....	40	.....	.....	25

Even on burns in full light the growth of Engelmann spruce is very slow. In Table 9 the average height after twenty-five years is but 98 inches, or about 8 feet.

These growth figures are all from measurements of trees growing in the open on cuttings or burns. In a dense stand growth is much slower. Under the usual conditions of density in this type, sixty years, or sometimes a much longer time, is required for a spruce seedling to reach a height of 18 inches.

In working out a plan of management it is fair to figure the rate of growth only from the time the seedlings are released by logging, and to disregard the period of suppression in the seedling stage. Thus, no matter what the age of the seedlings at the time the stand is cut over, they are considered as just starting and their subsequent growth calculated on that basis.

MANAGEMENT.

An Engelmann spruce forest should be managed as a protection forest. Selection cutting is the method now commonly used with the species, and under careful supervision it is, in most places, a distinct success. The species is tolerant and the stands are usually provided with abundant small growth as well as with trees of all sizes. Moreover, this method maintains the uniform forest cover that is so essential on high mountain slopes.

The main difficulty with the selection system is to restrict the cutting. Where the stands are of great commercial value, the temptation is to cut much more heavily than is best for the forest. It is, of course, more profitable to take all the large trees in one lumbering operation. Nevertheless, it should be clearly recognized that the heavy cutting of spruce over a large area is undesirable; it does more damage in the spruce type than in any of the associated types. Hence whenever profit can be made only by heavy cutting, no cutting at all should be done, since only the right kind of cutting will be beneficial. When, however, as in many stands, the proportion of desirable trees is limited, little effort will be required to restrict the amount of cutting, for there will be no profit in taking the undesirable trees. In ordinary spruce stands not more than one-third should be cut out, and in some places it would be preferable to cut not more than one-fourth.

In lodgepole pine-spruce mixtures, the spruce should be favored with few exceptions, since these mixtures form a transition type on situations where the natural evolution of the forest favors spruce and where lodgepole pine has come in mainly through fire. This may be done the more readily because it is often the policy in lumbering to cut the pine more heavily.

In Douglas fir-spruce mixtures the former should be favored because of its greater economic value, except when, as a result of fire, it is obviously on spruce ground, in which case the spruce should be favored.

Alpine fir, which is almost always present in the Engelmann spruce type, even in so-called pure stands, is probably as serviceable as spruce for protection purposes, but has far less commercial value. The stand is therefore improved by reducing the proportion of alpine fir. Cuttings made in the spruce type usually require the removal of all alpine fir of merchantable size, with the object of favoring the spruce. This object is, however, often defeated because alpine fir is more abundant in the reproduction than it is in the larger sizes.

Since alpine fir usually reaches its maturity and deteriorates before the spruce does, firs of large size are infrequent in the Engelmann spruce type. After lumbering by the selection system, however, the tendency is to release the abundant small alpine fir which has been favored by seed-bed conditions, and so to favor fir for many years at least.

It is obvious that the Engelmann spruce-alpine fir mixture presents an exceedingly difficult problem in forest management. Almost any cutting that is now practicable is certain to increase the proportion of fir, so it is likely that future stands will contain a larger proportion of alpine fir after lumbering.

The strip method of cutting has been suggested for the Engelmann spruce type, in order to change the seed bed from one that favors alpine fir seedlings to one that favors spruce. On limited areas narrow strips might be cut clean, between solid strips of the same width as those cut, and these could then be burned over lightly to remove the layer of dry humus which is responsible for the lack of spruce seedlings. The seed bed thus prepared would be seeded up to spruce from the adjoining solid strips. Under present market and lumbering conditions, however, the selection system is the only one adapted to the general condition of the Engelmann spruce forests.

The protective value of the forest decreases if the stand is opened up too much at a time; there is also the danger of exposing the seedlings to too intense sunlight and of drying out the soil so much that, because of their shallow root system, even the larger trees may suffer.

Old cutting areas show the bad results of heavy cutting in this type, especially in the more unfavorable places toward timber line. On such areas reproduction may be present, but invariably it will be found to have started under the old stand before the cutting. Where heavy cutting has been done in gulches and on moist flats reproduction is usually abundant as a direct result of the cutting.

BRUSH DISPOSAL.

As a general rule, all brush should be lopped and scattered. Piling and burning or piling without burning is rarely called for except within limited areas on fire lines or in places of extreme fire risk.

Moreover, the burning of brush is often followed by a prolific growth of weeds and grass that affords pasturage for sheep and other animals. After grazing begins there is little chance for young forest growth. A brush cover forbids interference by weeds or animals.

When flat on the ground, brush is a great protection to reproduction everywhere, but particularly on the duff-covered areas of selection cutting. Moisture is conserved at the surface, where it enables the spruce seedlings to germinate and finally reach through the duff to the mineral soil. The brush should lie flat, so that it will absorb moisture, and so decay more quickly, besides supplying more moisture to the seedlings.

In lodgepole pine-spruce mixtures any burning of the surface would tend to favor the pine at the expense of the spruce. Except on distinctly lodgepole-pine ground this result is undesirable and should be avoided.

Brush piles can not be burned without killing a large number of the young trees present in the openings. These young trees are the main dependence for the next crop; they are often sufficiently numerous to produce a fully stocked forest without the aid of reproduction which may follow cuttings.

On north slopes and moist situations brush, if properly lopped and scattered, decays rapidly; in a year or two it ceases to be a fire menace to the forest and is not likely to burn. On dry south slopes, however, brush may remain for many years without decaying, and when exceptionally thick it may be a source of danger from fire. In such situations piling and burning the brush would eliminate the fire danger.

In general, while there are situations in which the brush should be piled and burned, prevailing conditions of the spruce forests, as well as the improvement to the seed bed secured by lopping and scattering, make the latter method of brush disposal decidedly the proper one.

VOLUME.

As with all other species, the situation influences the height and form of the tree, and therefore the volume. The following tables are based upon a large number of representative trees measured in Colorado and Utah; they will apply in a general way to all spruce stands within this region. Of the trees measured the stump heights were from 1.5 to 3 feet and the top diameters from 6 to 8 inches inside the bark.

Table 12 gives the volume in board feet, Scribner Decimal C rule, for trees of various diameters and heights. Where the total heights

of the trees are known this table may be applied to any location in which Engelmann spruce grows.

TABLE 12.—*Board-foot volume of Engelmann spruce in Colorado and Utah, by diameter and total height.*

Diameter breast-high.	HEIGHT OF TREE—FEET.									Basis
	40.	50.	60.	70.	80.	90.	100.	110.	120.	
	VOLUME—BOARD FEET—SCRIBNER DECIMAL C RULE.									
Inches:										*Trees.*
8	15	20	30	.....	.....	.....	.....	.....	.....	8
9	15	25	35	50	70	.....	.....	.....	.....	19
10	20	30	45	60	80	.....	.....	.....	.....	19
11	25	40	55	70	90	110	.....	.....	.....	35
12	30	50	65	85	110	135	.....	.....	.....	45
13	40	60	80	100	130	160	.....	.....	.....	44
14	50	70	95	120	150	185	220	.....	.....	51
15	60	80	110	140	170	210	250	.....	.....	37
16	70	95	125	160	190	240	280	340	.....	61
17	.....	110	140	180	220	270	320	380	.....	57
18	.....	125	160	200	250	300	360	430	.....	55
19	.....	.....	180	225	280	330	400	470	.....	45
20	.....	.....	205	250	310	360	440	520	600	43
21	.....	.....	230	280	340	400	480	560	650	41
22	.....	.....	250	310	370	440	520	610	700	29
23	.....	.....	.....	340	400	480	560	660	760	21
24	.....	.....	.....	370	430	520	600	710	820	21
25	.....	.....	.....	.....	470	560	650	760	880	10
26	.....	.....	.....	.....	500	600	700	820	950	11
27	.....	.....	.....	.....	540	640	750	870	1,010	5
28	.....	.....	.....	.....	580	680	800	930	1,080	6
29	.....	.....	.....	.....	620	730	850	990	1,150	4
30	.....	.....	.....	.....	660	780	900	1,050	1,220	4
31	.....	.....	.....	.....	.....	830	960	1,120	1,300	3
32	.....	.....	.....	.....	.....	880	1,020	1,190	1,380	1
33	.....	.....	.....	.....	.....	930	1,080	1,260	1,460	.....
34	.....	.....	.....	.....	.....	980	1,140	1,330	1,540	1
35	.....	.....	.....	.....	.....	.....	1,200	1,400	1,620	.....
36	.....	.....	.....	.....	.....	.....	1,260	1,470	1,700	.....
37	.....	.....	.....	.....	.....	.....	.....	1,550	1,780	.....
38	.....	.....	.....	.....	.....	.....	.....	1,630	1,860	.....
Total	.....	.....	.....	.....	.....	.....	.....	.....	.....	676

Table 13, also based on diameter breast-high and total height, gives the volume in cubic feet.

TABLE 13.—*Cubic-foot volume*[a] *of Engelmann spruce in Colorado and Utah, by diameter and total height.*

Diameter breast-high.	HEIGHT OF TREE—FEET.									Basis.
	40.	50.	60.	70.	80.	90.	100.	110.	120.	
	VOLUME—CUBIC FEET.									
Inches:										*Trees.*
7	5.2	6.7	.....	.....	.....	.....	.....	.....	.....	5
8	6.4	8.2	10.0	11.9	.....	.....	.....	.....	.....	10
9	7.8	9.9	12.3	14.8	.....	.....	.....	.....	.....	17
10	9.5	12.0	14.7	17.8	21.0	.....	.....	.....	.....	19
11	11.6	14.5	17.6	21.0	24.8	28.5	.....	.....	.....	34
12	14.0	17.3	20.6	24.5	28.7	33.0	.....	.....	.....	42
13	.....	20.3	24.0	28.1	33.0	37.7	.....	.....	.....	43
14	.....	23.5	27.5	32.0	37.2	42.9	49.0	.....	.....	52
15	.....	.....	31.2	36.0	41.6	48.0	55.0	.....	.....	36
16	.....	.....	35.0	40.3	46.5	53.5	61.0	69.6	.....	60
17	.....	.....	39.0	45.0	51.6	59.0	67.5	76.7	.....	56
18	.....	.....	.....	49.6	56.8	65.0	74.2	84.0	.....	54
19	.....	.....	.....	54.0	62.0	71.0	81.0	92.0	.....	45

[a] Volumes excluding bark.

TABLE 13.—*Cubic-foot volume of Engelmann spruce in Colorado and Utah, by diameter and total height*—Continued.

Diameter breast-high.	HEIGHT OF TREE—FEET.									Basis.
	40.	50.	60.	70.	80.	90.	100.	110.	120.	
	VOLUME—CUBIC FEET.									
Inches:										*Trees.*
20				59.0	68.0	78.0	89.0	100.0	114.0	49
21					75.0	85.0	96.0	108.0	123.0	40
22					82.0	93.0	104.0	117.0	132.0	25
23					90.0	101.0	113.0	126.0	142.0	23
24					98.0	109.0	121.0	136.0	152.0	22
25						117.0	130.0	146.0	164.0	10
26						125.0	140.0	157.0	175.0	11
27						133.0	149.0	168.0	187.0	5
28						142.0	159.0	179.0	198.0	5
29						150.0	170.0	190.0	210.0	4
30						160.0	180.0	201.0	222.0	3
31						169.0	190.0	212.0	234.0	3
32						179.0	200.0	223.0	246.0	1
33						189.0	210.0	234.0	258.0	
34						199.0	220.0	245.0	271.0	1
35							231.0	257.0	284.0	1
36							241.0	268.0	296.0	
Total										676

Table 14 gives the number of trees of each diameter, breast-high, and total height necessary to scale 1,000 board feet by the Scribner rule. This table is computed from the board-foot volume table.

TABLE 14.—*Number of trees necessary to scale 1,000 board feet at various heights and diameters, Engelmann spruce in Colorado and Utah.*

Diameter breast-high.	HEIGHT OF TREE—FEET.								
	40.	50.	60.	70.	80.	90.	100.	110.	120.
	NUMBER OF TREES TO SCALE 1,000 BOARD FEET BY SCRIBNER RULE.								
Inches:									
8	70	50	33						
9	60	40	27	20	14.0				
10	50	32	22	17	13.0				
11	40	25	18	14	11.0	9.0			
12	32	20	15	12	9.0	7.0			
13	25	17	13	10	8.0	6.0			
14	20	14	11	8	7.0	5.0	5.0		
15	17	12	9	7	6.0	5.0	4.0		
16	14	11	8	6	5.0	4.0	3.6	3.0	
17		9	7	6	5.0	4.0	3.1	2.6	
18		8	6	5	4.0	3.3	2.8	2.3	
19			6	4	4.0	3.0	2.5	2.1	
20			5	4	3.0	2.8	2.3	1.9	1.7
21			4	4	3.0	2.5	2.1	1.8	1.5
22			4	3	3.0	2.3	1.9	1.6	1.4
23				3	2.5	2.1	1.8	1.5	1.3
24				3	2.3	1.9	1.7	1.4	1.2
25					2.1	1.8	1.5	1.3	1.1
26					2.0	1.7	1.4	1.2	1.1
27					1.9	1.6	1.3	1.1	1.0
28					1.7	1.5	1.3	1.1	.9
29					1.6	1.4	1.2	1.0	.9
30					1.5	1.3	1.1	1.0	.8
31						1.2	1.0	.9	.8
32						1.1	1.0	.8	.7
33						1.1	.9	.8	.7
34						1.0	.9	.8	.6
35							.8	.7	.6
36							.8	.7	.6
37								.6	.6
38								.6	.5

Table 15 gives the average volume, in board feet, for trees of various diameters and merchantable lengths, cutting to a specified top diameter.

TABLE 15.—*Volume, in board feet, by diameter and merchantable length, Engelmann spruce in Colorado and Utah.*

Diameter breast-high.	MERCHANTABLE LENGTH—FEET.										Basis.
	10.	20.	30.	40.	50.	60.	70.	80.	90.	100.	
	VOLUME—BOARD FEET—SCRIBNER DECIMAL C RULE.										
Inches:											*Trees.*
8	5	20	35	50							8
9	10	25	40	55	75						19
10	15	30	50	65	85						19
11	20	35	55	75	100	130					35
12	25	45	65	85	115	150	185				45
13	35	55	75	100	130	170	210				44
14	45	70	90	115	150	190	235	280			51
15		80	100	130	170	210	255	310	360		37
16		90	115	145	185	235	285	340	390	450	61
17			130	165	210	260	310	370	420	490	57
18			145	180	225	280	340	400	460	530	55
19			160	200	250	300	360	430	490	570	45
20					275	330	400	460	530	610	43
21					300	360	430	500	580	660	41
22					330	400	470	540	630	720	29
23					360	430	510	590	680	790	21
24					390	470	560	650	750	860	21
25					440	520	610	710	820	940	10
26					470	560	670	780	900	1,030	11
27					530	630	730	860	980	1,120	5
28					590	690	810	930	1,070	1,210	6
29						750	880	1,020	1,160	1,310	4
30						810	950	1,100	1,260	1,420	4
Total											671

Table 16 gives the average volume, in board feet, for trees of various diameters and number of 16-foot logs, cutting to a specified top diameter.

TABLE 16.—*Volume, in board feet, by diameter and number of 16-foot logs, Engelmann spruce in Colorado and Utah.*

Diameter breast-high.	NUMBER OF 16-FOOT LOGS.										Basis.
	1.	1.5.	2.	2.5.	3.	3.5.	4.	4.5.	5.	5.5.	6.	
	VOLUME—BOARD FEET—SCRIBNER DECIMAL C RULE.											
Inches:												*Trees.*
8	15	25	35									8
9	20	30	45	55								19
10	25	35	50	65	80							19
11	30	45	60	75	95	115						35
12	40	55	70	85	110	135	165					45
13	50	65	80	100	125	155	185	215				44
14		75	95	115	140	175	205	240	280			51
15		85	105	130	160	195	230	270	310	350		37
16			120	145	180	215	255	295	340	380	430	61
17			135	165	200	235	280	320	370	410	460	57
18				180	215	260	300	350	400	450	500	55
19				200	240	285	330	380	430	480	530	45
20					265	310	360	410	460	520	580	43
21					290	340	390	440	500	560	630	41
22						370	420	480	540	610	680	29
23						400	460	530	590	660	740	21
24							500	570	650	730	810	21
25							550	630	710	800	890	10
26								690	780	880	980	11
27								760	860	960	1,060	5
28									930	1,040	1,150	6
29									1,020	1,130	1,250	4
30									1,100	1,230	1,350	4
Total												671

CONCLUSIONS.

The Engelmann spruce type is distinctly a protection forest, and should be managed with the view of keeping the forest cover as complete as possible. In many cases, especially on steep slopes and near timber line, if the trees are of poor quality and of slow growth, there should be no cutting. At least two-thirds of the stand should be reserved for protection purposes, and heavy cuttings avoided at all times.

Alpine fir is the strongest competitor, because it is less exacting as to seed-bed conditions. This species should be cut as small as the market for its logs justifies, in order to check an increase in the proportion of alpine fir to Engelmann spruce.

Lodgepole pine associated with Engelmann spruce represents a transition stage in the development of the forest on ground which should naturally have a permanent spruce type. The cutting in this mixture should therefore favor the spruce. In Douglas fir-Engelmann spruce mixtures, the fir should be favored because of its greater economic value.

With few exceptions, brush left from logging in the Engelmann spruce type should be lopped and scattered.

On dry south exposures Engelmann spruce reproduction may be almost entirely lacking. It is possible, therefore, that seed-bed conditions and not light conditions explain the abundance of alpine fir seedlings at the expense of Engelmann spruce.

Approved:

JAMES WILSON,
Secretary of Agriculture.

WASHINGTON, D. C., *February 26, 1910.*

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